Comment on "First observation of doubly charmed baryon Ξ_{cc}^+"

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We speculate on a possible interpretation of events selected by the SELEX collaboration and stress an insufficient evidence for the observation of doubly charmed baryon.

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In the recent paper [1] the SELEX collaboration reported on the first observation of doubly charmed baryon. In this comment we argue the following:

1. Given the reported events would be caused by the doubly charmed baryons, the observed particle would have extremely exotic characteristics as concerns for the lifetime as well as the production rate and signature.

2. The events observed by the SELEX collaboration as described in [1] could be ordinary treated as associated pair production of charmed particles with no involvement of doubly charmed baryons.

In the analysis of SELEX data, the Λ_c^+ sample contains 1630 events with the full reconstruction of $\Lambda_c^+ \to pK^-\pi^+$ decay mode. It is important that the products of decay were identified by use of the Ring-Imaging Cherenkov detector (RICH), and the secondary vertex shifted from the interaction point of incoming particle with the target was resolved due to the silicon vertex detector. Further, the Cabbibo-allowed decay of $\Xi_{cc}^+ \to \Lambda_c^+ K^-\pi^+$ was searched for, and, thus, one expected the **strong correlation** of charged kaon-sign in decays of Λ_c^+ and Ξ_{cc}^+. The collaboration chosen to investigate the position of additional $K^-\pi^+$ vertex between the primary one and that of Λ_c^+. This condition could remove a lot of events under interest, but the further analysis in [1] shown that it is not so restrictive for the candidate events.

Let us assume that the SELEX collaboration can prove the observation of doubly charmed baryon Ξ_{cc}^+ as claimed in [1]. Then the measurement of Ξ_{cc}^+ lifetime in accordance with Table 1 in [1] shows the preferable value of 0.012 ps with the upper limit of 0.033 ps at the 90% confidence level. This result is in a deep contradiction with the theoretical predictions [2, 3] based on the Operator Product Expansion generalized to the systems composed of two heavy quarks and a single light quark. The total width of the doubly charmed baryon up to subleading terms is given by the sum of two basic terms. The first is the double total width of free charmed quark, i.e. the spectator contribution corrected by the coupled effects, which are mainly determined by the negative correction due to the time dilution of heavy quark motion in the rest frame of baryon,

$$\Gamma_c[\Xi_{cc}^+] \approx \Gamma_c^{\rm spect}\left(1 - \frac{\langle v_c^2\rangle}{2}\right).$$

The spectator width $\Gamma_c^{\rm spect}$ slightly depends on the normalization scale coming from the higher-order corrections in QCD, so that it is, with a good accuracy, independent of hadron state containing the charmed quark. Therefore, the value of $\Gamma_c^{\rm spect}$ cannot be essentially changed with respect to that of in D mesons. The averaged square of charmed quark velocity in the baryon can be estimated in the model-dependent way. Its value is about 0.15, which gives a typical size of subleading corrections. The second numerically-essential term in the total width of Ξ_{cc}^+ is determined by the weak rescattering of charmed and d quarks $\Gamma_{WS}[\Xi_{cc}^+]$. Its value parametrically depends on the wave function of baryon, which was in detail studied in Ref. [2]. Thus, the total width is equal to

$$\Gamma_{\rm tot}[\Xi_{cc}^+] \approx 2\,\Gamma_c[\Xi_{cc}^+] + \Gamma_{WS}[\Xi_{cc}^+],$$

where the numerical contribution of weak scattering contribution is about 60%. Then the lifetime is predicted by the estimate

$$\tau[\Xi_{cc}^+] = 0.16 \pm 0.05 \text{ ps},$$

which is much greater than the measured value for the candidates reported by the SELEX collaboration. Note, that the extremely short lifetime would point to the unexpected breaking of OPE in the doubly heavy baryons, since one should essentially change the mass of charmed quark as well as drastically enlarge the baryon wave function in contradiction with the description of hadrons containing a single charmed quark[1]. We have to emphasize that the analysis of lifetime in Ref. [2] was performed in a consistent way with the data on the lifetimes of baryons with the single charmed quark, i.e. Λ_c and $\Xi_c^{+,0}$. Thus,

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[1] The very strict and pessimistic approach to the accuracy of theoretical predictions for the lifetimes of hadrons with the charmed quark gives the uncertainty about 50%, but not the factor of 20.

the lifetime of candidates observed by the SELEX collaboration is extremely exotic for the doubly charmed baryon Ξ_{cc}^+. In addition, the measured lifetime is even shorter than the lifetime of so-called "sideband region" events (about 0.038 ps), and it is close to the single-event resolution of 0.020 ps.

Next, the production rate of selected candidates if they are really the events with the production of doubly charmed baryon, is extremely high. Indeed, the SELEX collaboration found that about 20% of Λ_c^+ events in its total sample are produced by Ξ_{cc}^+ [1]. The mechanism for the production of doubly charmed baryons in the strong interactions supposes the production of two pairs $c\bar{c}$, i.e. four heavy quarks (see review in [2]). At high energies of parton subprocesses as the gluon fusion $gg \to cc\bar{c}\bar{c}$ and the quark-antiquark annihilation $q\bar{q} \to cc\bar{c}\bar{c}$, the hard production of heavy quarks is suppressed in comparison with the production of single pair $c\bar{c}$ by the factor of 10^{-2}, that is smaller than the reported contents of doubly heavy baryons in the production of Λ_c^+. This theoretical expectation is strongly convinced, since it is based on the direct measurement of probability for the gluon splitting into the pair of $c\bar{c}$ by the L3, ALEPH and OPAL collaborations in the electron-positron annihilation at Z boson peak, where one got $P(g \to c\bar{c}) \sim 3 \cdot 10^{-2}$ [4]. In the process of gluon fusion dominant at the SELEX energies, the total energy in the parton subprocess is essentially less than the center-of-mass energy of hadron collisions because of the parton luminosity. In this way, the hard production supposes a strong threshold effect for four heavy quarks. This threshold suppression is significant for the energies of SELEX operation, so that it results in the additional factor of 10^{-2} [5, 6]. One should take into account the fact that the hadronization of four heavy quarks results in a fraction of doubly heavy baryons about 10%, since an essential part of events with two charmed quarks gives the production of two mesons or baryons each containing the single charmed quark[2]. Thus, the hard production mechanism gives the suppression of doubly heavy baryon production by the factor of 10^{-5} at the energies of fixed target experiments[3]. Another possibility is the production mechanism with the intrinsic charm contents in the initial hadrons [8]. In this case the threshold suppression is absent, but the normalization of intrinsic structure functions is suppressed by the factor of 10^{-2}, so that the production rate for the doubly charmed baryons is about 10^{-3} of the total charm rate. Anyway, the SELEX candidates for the doubly charmed baryon Ξ_{cc}^+ have exotically high production rate in comparison with theoretical expectations. Moreover, a low observed value of mean transverse momentum for Λ_c^+ from Ξ_{cc}^+ points to the preference of intrinsic charm mechanism, but with extremely high, and, hence, unacceptable, normalization of charm distribution in the initial hadrons. As for the signature of events with the Ξ_{cc}^+ candidates, the conservation of flavor in the strong interactions supposes the associative production of hadrons containing two anti-charmed quarks. These quarks should decay and produce two additional vertices shifted from the primary one as well as result in the additional charged multiplicity in the decays. The SELEX collaboration did not report on the enhancement of charged multiplicity in the selected evens or on the appearence of additional decay vertices. So, the question is where are two anti-charmed quarks? Do they preferably disappear by decays in the primary vertex with a low charged multiplicity? What is a probability of such the conditions?

The main problem of the interpretation is that the particle identification in the additional vertex of two charged particles was not possible, since the momenta were insufficient in order to reach the RICH. In this case the analysis loses the most strong evidence for the production of two charmed quarks in contrast to the dominant process with the yield of $c\bar{c}$ pair. This main process, then, can lead to the associative production of Λ_c^+ with the neutral anti-charmed particle decaying to two charged tracks of opposite signs with an unobserved neutral component lost by the silicon vertex detector as well as in the system of magnets. For example, the branching fraction of $\bar{D}^0 \to K^+\pi^-\pi^0$ is equal to $13.9 \pm 0.9\%$ [9]. In that case, since the neutral pion is lost from the analysis, one cannot reconstruct D^0, in part, its momentum. Therefore, one cannot draw a conclusion on the Lorentz-factor of the charmed meson in order to make some claims on its decay vertex[4]. Thus, there is no evidence against the ordinary treatment for the events reported by the SELEX collaboration in [1] as the associative production[5] of Λ_c^+ and $\bar{D}^0$. Moreover, the appropriate assignment of charged tracks leads to the $\Lambda_c^+ K^+\pi^-$ mass distribution presented in Fig. 2(b) of Ref. [1], where we can see a rather smooth histogram, which does not contain any significant peaks, but it exhibits a slow increase of events in the mass region of $3.7 - 4.0$ GeV. This behaviour could be expected if we suppose the associative production of Λ_c^+ with the

[2] The physical picture for such the suppression is quite transparent: the hard production of charmed quarks takes place in the volume about the Compton length cubed, while the baryon wave function determines the size of doubly charmed diquark by a transfer momentum $p \sim m_c \cdot v$ with the relative velocity of charmed quark motion $v \ll 1$, so that the probability of the baryon production is given by the ratio $p^3/m_c^3 \sim v^3 \ll 1$ in contrast to the continuum contribution formed by the hadrons containing a single heavy quark.

[3] We stress that the discrepancy of measured Ξ_{cc}^+ yield with the theoretical expectations reaches the value about 10^{-4}, while the result of BELLE [7] mentioned in [1] as concerns for the production rate for $J/\psi c\bar{c}$ disagrees within the factor of 10.

[4] At low momenta, the decay vertex of charmed meson could be rather close to the primary one.

[5] The associative production of Λ_c^+ and Ξ_c^0 decaying to $K^+\pi^-\bar{\Xi}^0$ is also possible, while the neutral anti-baryon further decays to $\bar{\Lambda}\pi^0$.

charmed particle, since in the case of full reconstruction one should observe an ordinary threshold distribution starting at the energy $M[\Lambda_c^+] + M[\bar{D}^0] \approx 4.1$ GeV, while the lose of neutral component in the decays of $\bar{D}^0$ results in the smearing of threshold effect at lower masses. Unfortunately, the SELEX collaboration did not present a comparison of mass distributions in the production of Λ_c^+ with the expected form calculated with a Monte Carlo generator well describing the events processed by the apparatus. Next, the number of Λ_c^+ events with the additional vertex is suppressed in comparison with the total rate of Λ_c^+. We do not find a direct claim on the number of events with the vertex separation greater than a fixed cut-off, so that we extract the amount of events under interest from the data on Fig. 2 in [1], where in the region of $3.2-4.0$ GeV one can count several hundreds events. The value of suppression is given by a typical efficiency for the reconstruction of additional vertex (something about several per cents), only, while one should expect a stronger suppression, because the production cross section for the doubly charmed baryons has to be significantly less than the cross section for the inclusive production of Λ_c^+. Finally, the wrong-assignment of kinematics can result in the fake peaks shown in Fig. 2 (a) and (c) of [1].

In conclusion, we show that the SELEX paper does not provide sufficient support for its claim of evidence for the observation of doubly charmed baryon Ξ_{cc}^+.

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